

EFFECT OF OPERATING PARAMETER ON PERFORMANCE OF WATER–LITHIUM BROMIDE VAPOUR ABSORPTION REFRIGERATION SYSTEM

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ABSTRACT

In this paper, the energy analysis of single effect water–lithium bromide vapour absorption refrigeration system (VARS) is presented. A commercial model having 350 TR capacities has been used for the parametric investigation of these systems. Here we had investigated the influences of operating temperature and effectiveness of heat exchanger on the thermal loads of components and coefficients of performance (COP). The results indicate that theoretical COP calculated based on the operating temperatures of VARS system lies in the range of 1.97–2.64 and actual COP calculated based on actual chilling effect produced by the chiller and thermal energy required in the generator of the VARS system lies in the range of 0.78–0.98 during the entire period of study. The values of efficiency of Low temperature heat exchanger (LTHE) and High temperature heat exchanger (HTHE) were observed between 43 % to 53 % and 70 % to 80 % respectively. It is also noticed that the higher efficiency of HTHE gave higher COP during the entire period of study. It is concluded that the COP_c values increases with increase in generator and evaporator temperatures, but decreases with increase in condenser and absorber temperature. As a result, it was found that the solution heat exchanger (SHE) and lower temperature of condensing having more effect on the investigated parameters than the other parameter.

KEYWORDS: Vapour Absorption Refrigeration System, Coefficients of Performance, Low Temperature Heat Exchanger, High Temperature Heat Exchanger, Solution Heat Exchanger

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INTRODUCTION

Generally, less importance is given to waste heat recovery from thermal energy in most of industries plant operations. Waste heat assisted vapour absoption refrigeration system (VARS) is gaining popularity because it increases energy independence and sustainability leaving no negative impact on the environment, it can be a good alternative of waste heat recovery from various sources of thermal energy. Vapor absorption refrigeration system (VARS) is widely used in different industry when low grade thermal energy is available and fuel is cheaper than electricity.

Vapour Absorption refrigeration system replaces the compressor with a generator and an absorber.

The absorber acts like the suction side of the compressor-it draws in the refrigerant vapour to mix with the absorbent (Stephan, 2004). A pump pushes the mixture of refrigerant and absorbent up to the high-pressure side of the system. The generator delivers the refrigerant vapor to the rest of the system (patek *et al.*, 1995). The refrigerant vapor leaving the generator enters the condenser, where heat is transferred to water at a lower temperature, causing the refrigerant vapor to condense into a liquid. Therefore, it produces refrigeration effect in evaporator (Butz *et al.*, 1989; Fan *et al.*, 2007).

In the 1950's, a system using water-lithium bromide as the working fluid was introduced for industrial applications. In these systems water is used as refrigerant and a solution of lithium bromide in water is used as absorbent (Castro *et al.*, 2002). Since water is used as refrigerant, using these systems it is not possible to provide refrigeration at sub-zero temperatures. Hence it is used only in applications requiring refrigeration at temperatures above 0°C. In 1859, Ferdinand Carre introduced a novel machine using water-ammonia as the working fluid. As mentioned earlier, in this system ammonia is used as refrigerant and water is used as absorbent. The advantages of VARS are Chlorofluorocarbons (CFCs) free, eco-friendly technology and system runs on low grade waste heat.

Srikhirin *et al.* (2001) show the C.O.P of the single effect and double effect vapour absorption refrigeration system are reported as 0.6-0.8 and 0.8-1.0 respectively. The literature review revealed that research and development efforts on multi-effect cycles found considerable promise for future application. The usage of vapour absorption refrigeration system using of low grade waste heat and design up-gradation of various components have made it economical in commercial plant. The information generated in this study would provide basic knowledge of how to evaluate the performance of the VARS plant and optimization of operating parameter. It is expected that this contribution will simulate wider interest in the technology of absorption refrigeration system.

EXPERIMENTAL SET UP

The commercial Water-LiBr plant having installed capacities of 350 TR was selected for the study. The commercial Water-LiBr chilling system uses the waste exhaust heat of the power plant for supply of thermal energy at the generator of system show in figure 3 & 4. (Plant capacity: 350 TR, Fuel: waste heat of thermal power plant). The power plant produces flue gases at a temperature of in the range of 150-160 °C. The waste heat assisted refrigeration plant consists of Generator, Evaporator, Absorber, **Condenser** and Heat Exchangers show in the figure No 1. The system has PLC based control system in order to regulate the flow rate of chilled water, flue gases, concentration of LiBr solution etc. The vapour absorption heat pump functions in two modes namely Simultaneous Heating Cooling Mode and Cooling Mode.

Evaporator

The evaporator consists of a tube bundle, an outer shell, distribution trays and a refrigerant pan. In the cycle, a refrigerant pump circulates the refrigerant from the refrigerant pan into the distribution trays. From the trays, the refrigerant falls on the evaporator tubes. The shell pressure is very low (<6mmHg). At this pressure the refrigerant evaporates at a low temperature (<3.7°C) and extracts latent heat of evaporation from the water being circulated through the evaporator tubes. Thus, the heat is extracted from the water being circulated through the tubes and it becomes chilled.

Absorber

The absorber consists of a tube bundle, an outer shell (common with the evaporator), distribution trays and an absorbent collection sump. Concentrated absorbent solution (<63.4%) from the high temperature generator is fed into the distribution trays. This solution falls on the absorber tubes. Concentrated absorbent has an affinity to water. Hence, the

vaporized refrigerant from the evaporator section is absorbed. Due to this absorption the vacuum in the shell is maintained at a low pressure, and ensures the heat extraction from the heat source water. The concentrated absorbent becomes diluted. The diluted absorbent concentration is ($\approx 57.5\%$) collects in the bottom of the shell.

Generator

The diluted absorbent flows around these tubes and is heated by waste heat of thermal power plant. The temperature of the solution increases until it reaches the boiling point. The refrigerant water boils out of the solution. The solution concentration increases (to $\approx 63\%$). This increased concentration is referred to as the strong concentration. Further, Concentrated absorbent solution ($\approx 63.4\%$) from the low temperature generator is fed into the distribution trays.

Condenser

The function of condenser is to condense the refrigerant vapors in this commercial plant. Inside the condenser, cooling water flows through tubes and the hot refrigerant vapor fills the surrounding space. At present system, the water from the cooling tower first passes through the absorber for the increasing the absorption capacity of strong LiBr solution and then goes to the condenser.

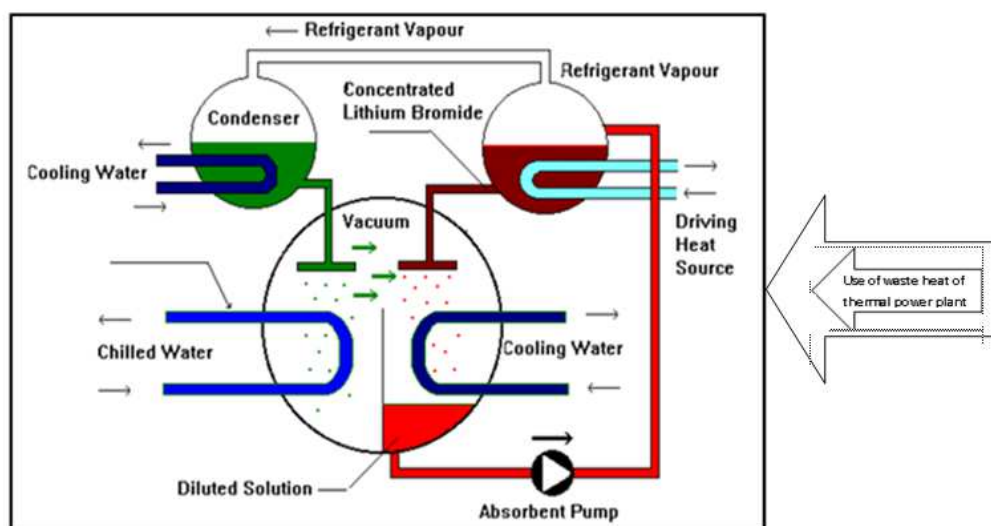


Figure 1: Water-Lithium Bromide Vapours Absorption Refrigeration System

METHODOLOGY

The trials were conducted in the month of February, March and April 2013 for evaluation of performance of vapor absorption machine (VAM) plant. During the trials, the chilling effect data conducted in day shift and night shift for the better comparisons of environmental effect of performance. The operation of the plant is involved in various (1st shift, 2nd shift and 3rd shift) shift wise, so we evaluated the effect of different operating parameter on performance evaluation is carried out in different shift wise. The performance of the experimental VAM plant was evaluated under the following conditions.

- **Chilling Effect:** 1st shift, 2nd shift and 3rd shift
- **Operating Seasons:** February, March and April, 2013

In the experimental unit, the rate of energy balance at evaporator, condenser, generator and absorber is estimated

by using standard heat and mass transfer equation. Analysis of the system is carried out with the following assumptions:

- Changes in potential and kinetic energies across each component are negligible
- No pressure drops due to friction
- Only pure refrigerant boils in the generator

In the experimental unit, the nomenclatures followed are:

m = mass flow rate of refrigerant, kg/s

m_{ss} = mass flow rate of strong solution (rich in LiBr), kg/s

m_{ws} = mass flow rate of weak solution (weak in LiBr), kg/s

The circulation ratio (λ) is defined as the ratio of strong solution flow rate to refrigerant flow rate. It is given by:

$$\lambda = m_{ss}/m = (\xi_{ss} - \xi_{ws})$$

ξ_{ws} = mass fraction of weak solution.

ξ_{ss} = mass fraction of strong solution

The analysis is carried out by applying mass and energy balance across each component. In the Figure 2 shows the schematic experimental unit of the system that indicating various state points.

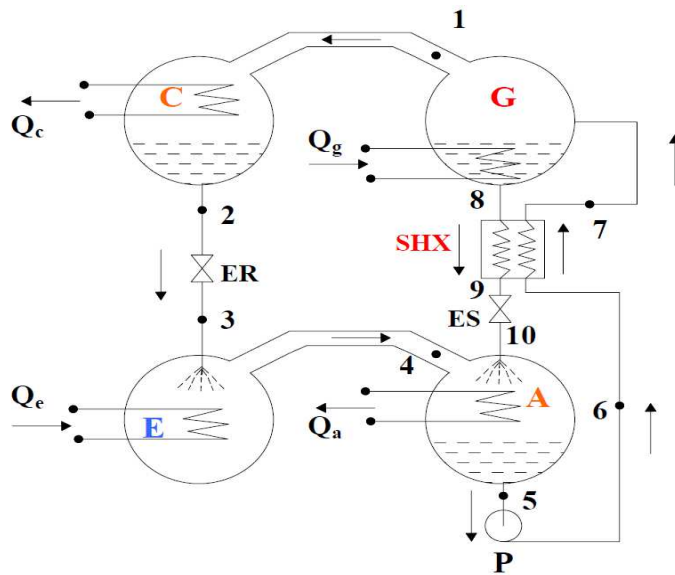


Figure 2: Schematic Diagram of Waste Heat Assisted VARS

Energy Analysis Equation of Condenser

The condenser energy analysis is carried out by applying mass and energy balance equation.

$$m_1 = m_2 = m$$

$$Q_c = m (h_1 - h_2)$$

m = mass flow rate of refrigerant (kg/s).

h_1 = the enthalpy of superheated water vapors before entering to condensers (kW).

h_2 = the enthalpy of water after living to condensers (kW).

Energy Analysis Equation of Evaporator

In the experimental unit, the evaporator's energy analysis is carried out by applying mass and energy balance equation.

$$m_3 = m_4 = m$$

$$Q_e = m (h_4 - h_3)$$

h_4 = the enthalpy of water vapor after living the evaporator (kW).

h_3 = the enthalpy of water refrigerant to entering the evaporator (kW).

energy analysis equation of absorber

The absorber energy analysis is carried out by applying mass and energy balance equation.

$$m + m_{ss} = m_{ws}$$

$$m_{ss} = \lambda m \leftrightarrow m_{ws} = (\lambda + 1) m$$

From mass balance for pure water:

$$m + (1 - \xi_{ss}) m_{ss} = (1 - \xi_{ws}) m_{ws}$$

$$\lambda = \xi_{ws} / (\xi_{ss} - \xi_{ws})$$

$$Q_a = m h_4 + \lambda m h_{10} - (\lambda + 1) m h_5 \text{ or,}$$

$$Q_a = m [(h_4 - h_5) + \lambda (h_{10} - h_5)]$$

Where,

m = mass flow rate of refrigerant (kg/s).

h_4 = Enthalpy of vapour refrigerant in evaporator (kJ/kg).

h_5 = Enthalpy of weak refrigerant (H₂O- LiBr) mixture at after evaporator (kJ/kg).

h_{10} = Enthalpy of strong solution (H₂O- LiBr) mixture spray to absorber (kJ/kg).

The first term in the above equation $m(h_4 - h_5)$ represents the enthalpy change of water as changes its state from vapour at state 4 to liquid at state 5. The second term $m\lambda(h_{10} - h_5)$ Represents the sensible heat transferred as solution at state 10 is cooled to solution at state 5.

ENERGY ANALYSIS OF EQUATION GENERATOR

The generator energy analysis is carried out by applying mass and energy balance equation.

$$m_3 = m_4 = m$$

Heat input to the generator is given by:

$$Q_g = m h_1 + m \lambda h_8 - (1 + \lambda) m h_7 \text{ or,}$$

$$Q_g = m [(h_1 - h_7) + \lambda (h_8 - h_7)]$$

In the above equation the 1st term on the RHS $m(h_1 - h_7)$ represents energy required to generate water vapor at state 1 from solution at state 7 and the 2nd term $\lambda m(h_8 - h_7)$ represents the sensible heat required to heat the solution from state 7 to state 8.

Where,

m_{ss} = mass flow rate of strong solution (kg/s).

m_{ws} = mass flow rate of weak solution (kg/s).

h_1 = enthalpy of superheated water vapors before entering to condensers (kW).

h_8 = Enthalpy of strong solution to exit of generator (kW).

h_7 = Enthalpy of weak solution at the exit of solution HTHE (kW).

In order to find the performance of the experimental VARS system from the above set of equations, we observed the data of the operating temperatures, weak and strong solution concentrations, effectiveness of solution heat exchanger and the refrigeration capacity. It is generally assumed in this experimental study the solution at the exit of absorber and generator is at equilibrium so that the equilibrium P-T- ξ and h-T- ξ charts can be used for evaluating solution property data.

DETERMINATION OF THEORETICAL C.O.P

The derivation of the equation used for calculation COP_{max} (or COP_{carnot}) is given below.

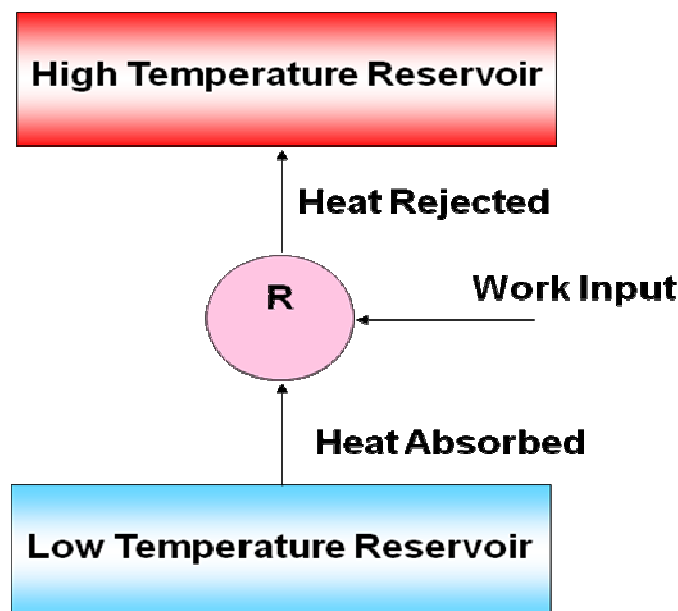


Figure 3: Refrigeration Cycle

Figure A.1.1: Heat input and output of vapor absorption refrigerating cycle

The total heat rejected at condenser (Q_c) at T_c temperature is equal to the sum of heat supplied at generator (Q_g) at T_g and the refrigerating effect (Q_e) produced at T_e , neglecting the pump work and other heat losses. Thus according the first

law of thermodynamics:

$$\therefore Q_c = Q_g + Q_e$$

As the vapor absorption refrigeration system can be considered reversible system, the initial entropy of the system is equal to the entropy of the system after the changes in the conditions.

$$\therefore \frac{Q_c}{T_c} = \frac{Q_g}{T_g} + \frac{Q_e}{T_e}$$

$$\therefore \frac{Q_g}{T_g} + \frac{Q_e}{T_e} = \frac{Q_g}{T_c} + \frac{Q_e}{T_c} \quad [\text{from equation} \quad . (1)]$$

$$\therefore \left[\frac{T_c - T_g}{T_g * T_c} \right] = Q_e \left[\frac{T_e - T_c}{T_e * T_c} \right]$$

$$Q_g = Q_e \left[\frac{T_e - T_c}{T_e * T_c} \right] * Q_g \left[\frac{T_g * T_c}{T_c - T_g} \right]$$

$$Q_g = Q_e \left[\frac{T_c - T_e}{T_e * T_c} \right] * Q_g \left[\frac{T_g * T_c}{T_g - T_c} \right]$$

$$Q_g = Q_e \left[\frac{T_c - T_e}{T_e} \right] * Q_g \left[\frac{T_g}{T_g - T_c} \right]$$

Maximum COP of the system is give by

$$\therefore (\text{COP})_{\max} = \frac{Q_e}{Q_g}$$

$$= \frac{Q_e}{Q_e \left[\frac{T_c - T_e}{T_e} \right] \left[\frac{T_g}{T_g - T_c} \right]}$$

$$= \left[\frac{T_c}{T_c - T_e} \right] \left[\frac{T_g - T_c}{T_g} \right]$$

The expression $\left[\frac{T_c}{T_c - T_e} \right]$ represent the Carnot COP of a refrigerator operating between T_c and T_e , while the expression $\left[\frac{T_g - T_c}{T_g} \right]$ represented efficiency of Carnot engine working between temperature of T_g and T_c . In case the heat is rejected at different temperature, condensers and absorber $(\text{COP})_{\max} = \left[\frac{T_c}{T_c - T_e} \right] \left[\frac{T_g - T_a}{T_g} \right]$ where, T_a = temperature at which Q_a is rejected in the absorber.

Here, the sample calculation of theoretical COP of the VARS is given by the

$$= \left[\frac{T_e}{T_c - T_e} \right] \left[\frac{T_g - T_a}{T_g} \right]$$

Determination of Actual C.O.P

The actual co-efficient of performance (COP_{act}) is the ratio of the actual refrigerating effect produced to the actual work of generator of the system. The actual refrigerating effect produced during the experimental trials was calculated as under.

$$R = m \times s \times \Delta t$$

Where,

R = Refrigerating effect produced, kJ/h

m = Mass of the material cooled, kg

s = Specific heat of the material cooled, kJ/kg K

Δt = Difference between initial and final temperature of the material, °C

The actual work of generator was measured by connecting digital energy meter.

$$COP_{act} = \frac{\text{Refrigerating effect produced, kJ/h}}{\text{Actual work of generator, kJ/h}}$$

Efficiency of Heat Exchanger

Efficiency of heat exchanger is a play major role to increase the performance of the VARS. Using of Solution Heat Exchanger the temperature of cold fluid increases before entering to the generator, so there is less heat input required in the generator for rejection of heat from diluted LiBr solution and hence COP of system is increases.

$$n(\%)_{HE} = \frac{T7 - T6}{T8 - T6}$$

Where,

T7 = outlet temperature of heat exchanger, °C

T6 = inlet temperature of heat exchanger, °C

T8 = inlet temperature of heating medium, °C

From the above equation, the temperature of the weak solution entering the generator (T7) can be obtained since T6 is almost equal to T5 and T8 is equal to the generator temperature T_g . The temperature of superheated water vapour at state one may be assumed equal to the strong solution temperature T_g .

COOLING TOWER LOAD

In VAM plant to find out the rate of heat rejected at cooling tower is the measure of cooling tower capacity.

Cooling tower load (kJ/h)	=	Mass flow rate of water, kg/h	×	Specific heat of water, kJ/kg K	×	($t_1 - t_2$)
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Where,

t_1 = temperature of water entering the cooling tower, °C

t_2 = temperature of water leaving the cooling tower, °C

The efficiency of cooling tower is calculated by using the equation as under.

$$\% \eta = \frac{\text{Actual drop in dbt}}{\text{Ideal drop in dbt}} \times 100 = \frac{t_1 - t_2}{t_1 - wbt} \times 100$$

Where,

wbt_1 = wbt of entering air (on windward side).

t_1 = temperature of water entering the cooling tower, °C

t_2 = temperature of water leaving the cooling tower, °C

RESULTS AND DISCUSSIONS

Effect of Condensing Temperature

In the VARS, the mechanical draft-cooling tower is used for cooling of water to be used for the condenser. The values of condensing temperature ranged from 28.8 to 30.5 °C, 28.85 to 29.5 °C and 29.8 to 31 °C for the months of February, March, and April 2013 respectively. The effect of the condensing temperature on refrigeration effect for the month of February, March, and April 2013 is indicated in Figure 4.1, 4.2, 4.3. It is found that when the condensing temperature decreased, the refrigeration effect produced by VARS is also increased.

It is desirable to operate the VARS at lower condensing temperature to get higher cooling capacities of the system. In the present system, the temperature of water used at the condenser depends on the efficiency of cooling tower as well as the rise in temperature of water in the absorber. The flow rate of chilled water in the evaporator was steady at 120 kg/s during the entire period of study. Therefore, the temperature drop achieved in chilled water decides the cooling effect produced by the VARS.

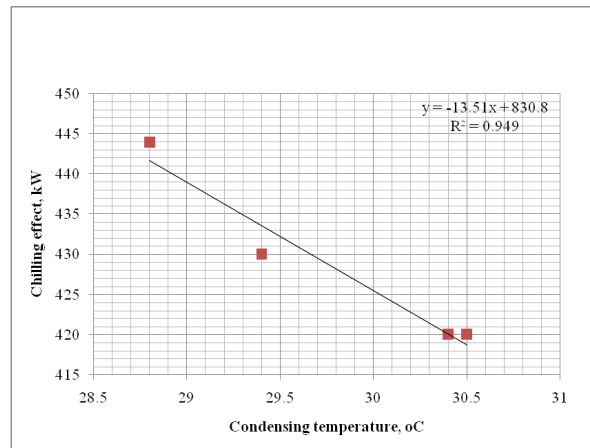


Figure 4.1: Effect of Condensing temperature on Refrigeration Effect of VARS in the Month of February, 2013 (Day Shift)

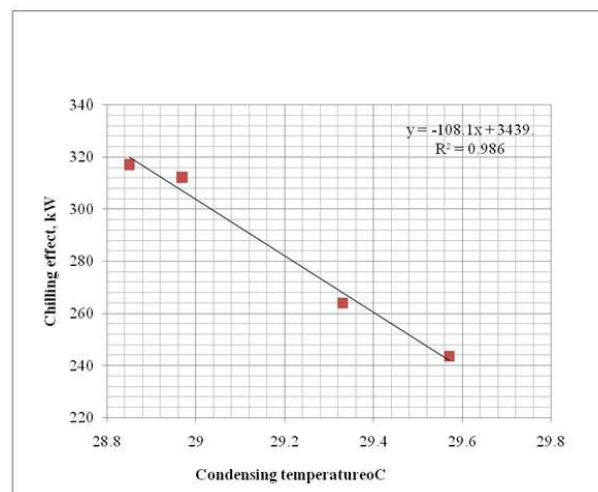


Figure 4.2: Effect of Condensing temperature on the Refrigeration Effect of VARS in the Month of March, 2013 (Day Shift)

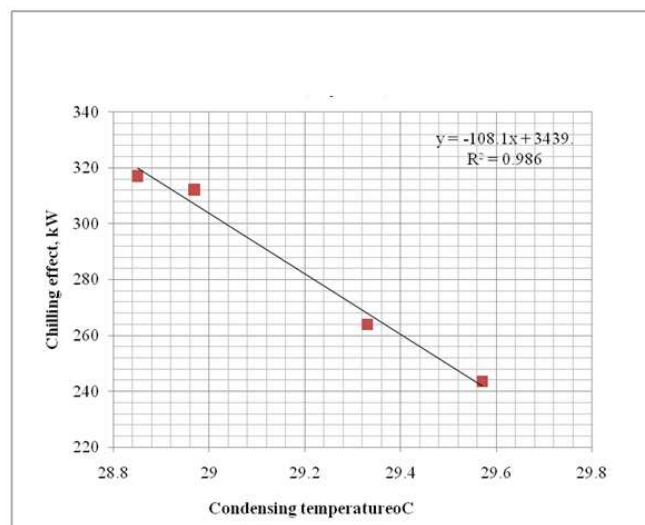


Figure 4.3: Effect of Condensing temperature on the Refrigeration Effect of VARS in the Month of April, 2013 (Day Shift)

Effect of Environmental Conditions

The VARS was operated under the average environmental conditions of 31.0°C dbt & 23.5 °C wbt, 34.5 °C dbt & 26.0 °C wbt and 37.0 °C dbt & 26.5 °C wbt in the month of February March and April 2013 respectively. Though, the values of dry bulb and wet bulb temperature of the ambient air vary considerably during day and night shift. The environmental condition is one of the factors affecting on the performance of cooling tower. The lower temperature of condenser water is desirable to get the better performance of the VARS.

Theoretical Cop

The values of theoretical COP of the VARS obtained during the operation of the plant in the month of February, 2013 ranged from 2.52 to 2.34 and 2.64 to 2.34 for day and night shift respectively. The lower condensing temperature gave higher COP values in the month of February, March, and April 2013. Theoretical COP values of the VARS obtained during the operation of the plant in the month of March, 2013 ranged from 2.12 to 2.36 and 2.23 to 2.40 for day and night shift respectively. As the temperature of water used for condenser was lower, the COP values were higher in the month of March, 2013. The values of COP_{th} obtained during operation of VARS in day and night shift ranged between 1.97 & 2.14 and 2.05 & 2.36 respectively in the month of April 2013. It been observed that the COP value in night shift is higher than day shift due to lowering temperature of condenser in night shift compare to day shift.

Actual Cop

Higher COP is desirable to get more cooling effect in relation to work of generator. The values of actual COP of the VARS during the month of February 2013 ranged from 0.93 to 0.97 and 0.93 to 0.98 in day and night shift respectively. It is found that operation of VARS with low condensing temperature gave higher COP values in the month of February, 2013. Similarly, actual COP values of the VARS obtained during the month of March and April 2013 ranged from 0.84 to 0.91, 0.78 & 0.85 in day shift and 0.96 to 0.892, 0.82 & 0.91 in night shift respectively.

Relationship between Cop of VARS and Efficiency of LTHE

The values of efficiency of low temperature heat exchanger obtained during the months of January, February and March, 2013. It was noticed from the relationship between COP and the values of efficiency of LTHE that as the efficiency of LTHE increases, the COP values were higher in all the weeks in the month of February, March and April 2013. The effect of HTHE efficiency on the COP during different weeks in the month of February, March and April 2013 is depicted in Figure 4.4, 4.5 and 4.6.

The LTHE is used to pre-heat the weak LiBr solution with the help of strong LiBr solution coming from generator of VARS. The higher efficiency gives higher temperature of the weak LiBr solution resulting into the lower thermal energy requirement in the generators. It is further possible to improve the performance of VARS by improving the design and optimization of LTHE.

Relationship between Cop of VARS and Efficiency of HTHE

It was noticed from the relationship between COP and the values of efficiency of HTHE that as the efficiency of HTHE increases, the COP values were higher in all the weeks in the month of February, March and April 2013. The effect of HTHE efficiency on the COP during different weeks in the month of February, March and April 2013 is depicted in Figure 4.4, 4.5 and 4.6.

The HTHE is used to pre-heat the intermediate LiBr solution with the help of strong LiBr solution coming from generator of VARS. The higher efficiency gives higher temperature of the weak LiBr solution resulting into the lower thermal energy requirement in the generators. It is further possible to improve the performance of VARS by improving the design and optimization of LTHE.

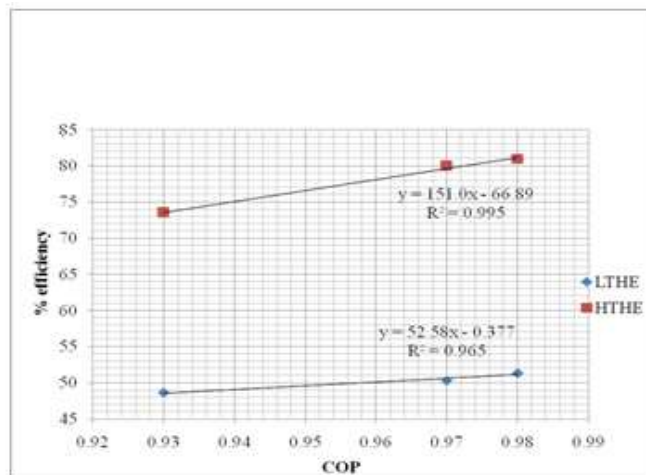


Figure 4.4: Relationship between COP of VARS and Efficiency of LTHE & HTHE in the Month of February, 2013

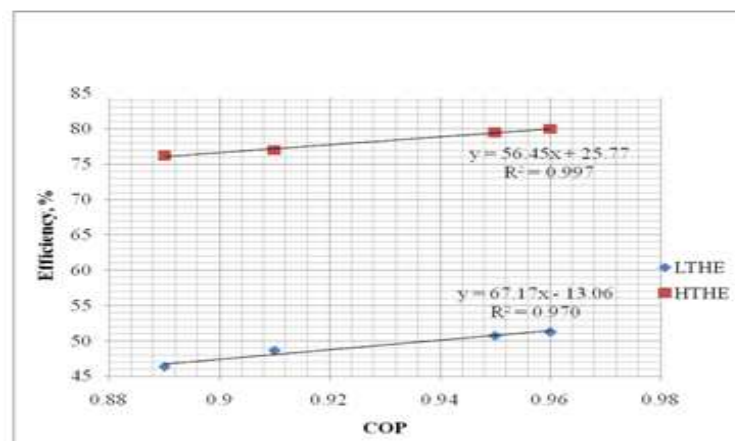


Figure 4.5: Relationship between COP of VARS and Efficiency of LTHE & HTHE in the Month of March, 2013

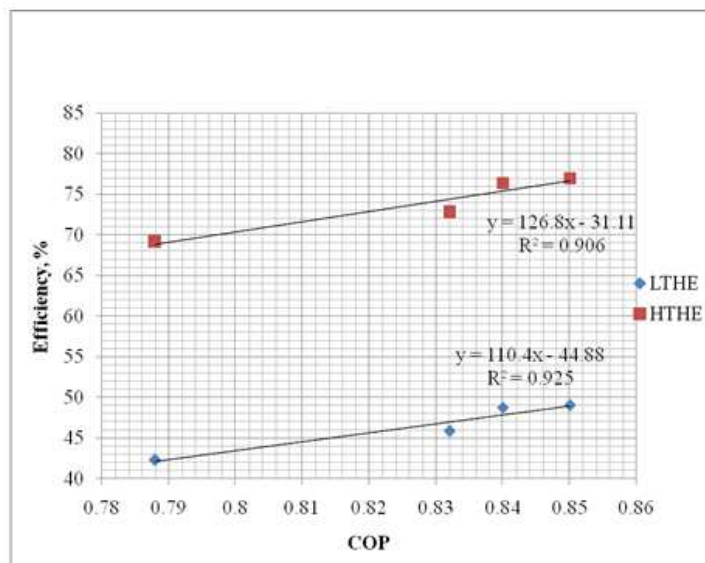


Figure 4.6: Relationship between COP of VARS and Efficiency of LTHE & HTHE in the Month of April, 2013

Effect of Efficiency of Cooling Tower on the Performance of VARS

The effect of efficiency of cooling tower on the performance of VARS during the month of February, March and April, 2013 ranged from 61.1 to 62.5 %, 55 to 37.5 to 62.5% and 55.5 to 62.5% in day shift, respectively. It has been observed that higher efficiency of cooling tower giving the higher COP values during the entire period of study.

It has been noticed that as the efficiency of cooling tower increased, the COP of the plant also showed increasing trend. The water cooled in the cooling tower first goes in the absorber for the maintaining the lower temperature of strong LiBr solution. It is necessary to maintain lower temperatures of LiBr in the absorber in order to increase the absorbing capacity of the absorbent. The cooling water from the absorber further goes to condenser. Therefore, the temperature of water leaving the cooling tower and condensers cooling medium temperature are different in the plant. It is desirable to maintain the lower temperature of cooling medium of the condensers, however in the present plant the water is first passing through absorber leading to about 3 to 4 °C rise in temperature of the water. The condensers temperature was constant at 31°C during all 3 months of study period.

CONCLUSIONS

The following conclusions have been derived from the study.

The statistical analysis revealed that variation in the condensing temperature during operation of the VARS was very narrow ranging from 26.7 to 31.0 °C during the entire period of the study as the water cooled in the cooling tower is first passes through absorber of the plant before being used at the condenser. It is found from the observed data that lower condensing temperature increased the refrigerating capacity of the VARS during the entire period of study. The regression equations obtained between refrigerating effect produced and temperature of condenser, were $Y = -13.51x + 830.8$ ($R^2 = 0.949$), $y = -20.21x + 1005$ ($R^2 = 0.935$) and $y = -108.1x + 3439$ ($R^2 = 0.986$) for the month of February, March and April, 2013 respectively, in day shift. Whereas the corresponding equations of obtained between refrigerating effect produced and temperature of condenser were $Y = -19.73x + 870.8$ ($R^2 = 0.832$), $y = -6.285x + 473.4$ ($R^2 = 0.852$) and $y = -6.829x + 488.2$ ($R^2 = 0.914$) for the night shift. These regression equations are quite useful to predict the performance of

VARs.

The operating generator temperature is very critical as it governs the capacity of the plant and the performance of the plant in terms of COP. The temperature of generator was regulated by PLC based temperature controller in order to regulate the damper position which regulates the flow rate of flue gases. The values of generator temperature ranged from 128.8 to 132.6 °C, 123.2 to 131.6 °C and 121.9 to 130.0 °C for the months of February, March and April 2013 respectively during operation of VARs in day shift.

The efficiency of LTHE of the VARs obtained during in the month of February, March and April, 2013 ranged from 48.6 to 51.3%, 46.34 to 51.28% and 42.30 to 48.78% respectively. It is noticed from the relationship between COP and the values of efficiency of LTHE that higher efficiency of LTHE gave higher COP of VARs and vice versa. The higher efficiency of LTHE gave higher temperature of the weak LiBr solution resulting into the lower thermal energy requirement in the generators. The regression equations obtained between COP and efficiency of LTHE, were $Y = 52.58x - 0.377$ ($R^2 = 0.965$), $y = 67.17x - 13.06$ ($R^2 = 0.970$) and $y = 110.4x - 44.88$ ($R^2 = 0.925$) for the month of February, March and April, 2013 respectively. The regression equations obtained are quite useful to predict the relationship between LTHE and COP of VARs.

The efficiency of HTHE of the VARs obtained during in the month of February, March and April, 2013 ranged from 73.5 to 81%, 73.52 to 80% and 69.13 to 76.4%, respectively. It is noticed from the relationship between COP and the values of efficiency of HTHE that higher efficiency of HTHE gave higher COP during the entire period of study. The regression equations obtained between COP and efficiency of HTHE, were, $y = 151.0x - 66.89$ ($R^2 = 0.995$), $y = 56.45x + 25.77$ ($R^2 = 0.997$) and $y = 126.8x - 31.11$ ($R^2 = 0.906$) for the month of February, March and April 2013 respectively. The regression equations obtained are quite useful to predict the relationship between HTHE and COP of VARs.

The efficiency of cooling tower of the VARs obtained during in the month of February, March and April, 2013 ranged from 61.1 to 62.5 %, 55 to 37.5 to 62.5% and 55.5 to 62.5% in day shift, respectively. It has been noticed that as the efficiency of cooling tower increased, the COP of the plant also showed increasing trend. It is necessary to maintain lower temperatures of LiBr in the absorber in order to increase the absorbing capacity of the absorbent. The cooling water from the absorber further goes to condenser. It is desirable to maintain the lower temperature of cooling medium of the condensers, however in the present plant the water is first passing through absorber leading to about 3 to 4 °C rise in temperature of the water. And consequently it has been observed that lower condensing temperature give higher COP during the entire period of study.

The values of theoretical COP calculated based on the operating temperatures of the VARs range from 1.97 to 2.64 during the entire period of study based on the variation of condensers and generator temperatures. The values of actual COP calculated based on actual chilling effect produced by the chiller and thermal energy required in the generator of the VARs ranged from 0.78 to 0.98 during the entire period of study.

It is suggested to improve the performance of the condenser by supplying cooling water directly from the cooling tower to the condenser. At present, the water from the cooling tower first passes through the absorber and then goes to the condenser. The water required for the absorber can be supplied separately either from a separate cooling tower or by increasing the capacity of the existing cooling tower



Figure 3: Commercial Unit of VARS



Figure 4: Commercial Unit of Thermal Power Plant

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